RADC-TR-71-256
Technical Report
January 1971

Prepared By
Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York 13440

PROJECT SECEDE

AERONOMIC STUDIES FOR SECEDE
SECEDE II ROCKET PROBE EXPERIMENT

Aeronomy Corporation
P. O. Box 2209 Station A
Champaign, Illinois 61820

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 1057

21

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related government procurement operation, the government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded, by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Do not return this copy. Retain or destroy.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Aeronomy Corporation P.O. Box 2209, Station A Champaign, Illinois 61820	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Aeronomic Studies for SECEDE: SECEDE II Rocket Probe Experiment

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Interim Report

5. AUTHOR(S) (First name, middle initial, last name)

S.A. Bowhill

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1971	14	5

8a. CONTRACT OR GRANT NO. F30602-70-C-0174 b. PROJECT NO. ARPA Order 1057 c. Program Code 1E20 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) RADC-TR-71-256

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES MONITORED BY: JOSEPH J. SIMONS RADC/OCSE Griffiss AFB NY 13440	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency 1400 Wilson Blvd Arlington VA 22209

ABSTRACT

In order to resolve questions as to the dynamical behavior of high-altitude barium releases, a rocket probe payload has been designed and flown involving measurements of electron and ion density, electron temperature, and electric field. Six of these rockets were prepared for firing during the SECEDE II Test Series in January 1971. Some studies have also been made of analytical models for the electron density in a striated barium cloud, aimed at determining the effect of striation superposition on their visibility.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rocket Probe						
Barium Cloud						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

UNCLASSIFIED
Security Classification

AERONOMIC STUDIES FOR SECEDE
SECEDE II ROCKET PROBE EXPERIMENT

S. A. Bowhill

Contractor: Aeronomy Corporation
Contract Number: F30602-70-C-0174
Effective Date of Contract: 19 January 1970
Contract Expiration Date: 18 January 1971
Amount of Contract: $45,047.00
Program Code Number: 1E20

Principal Investigator: Dr. S. A. Bowhill
Phone: 217 359-8007

Project Engineer: Vincent J. Coyne
Phone: 315 330-3107

Contract Engineer: Joseph J. Simons
Phone: 315 330-3451

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by Joseph J. Simons, RADC (OCSE), GAFB, NY 13440 under Contract No. F30602-70-C-0174.

ABSTRACT

In order to resolve questions as to the dynamical behavior of high-altitude barium releases, a rocket probe payload has been designed and flown involving measurements of electron and ion density, electron temperature, and electric field. Six of these rockets were prepared for firing during the SECEDE II Test Series in January 1971. Some studies have also been made of analytical models for the electron density in a striated barium cloud, aimed at determining the effect of striation superposition on their visibility.

TABLE OF CONTENTS

1. Introduction

Aeronomy Corporation participation in the SECEDE program has been directed towards arriving at a realistic model of a striated barium cloud. In addition to participating in the design of the transmission experiment, principal attention has been paid to the development of a rocket probe payload for direct measurement of barium cloud parameters.

In order to set up an adequate physical model of barium cloud motion and striation, it is necessary to have available a number of parameters of the barium cloud, some of which are not readily deduced from optical or remote RF measurements. These include:

(1) Absolute electron density in the cloud. The RF transmission experiment and optical measurements can, at best, give the electron density integrated along the line of sight. Deducing an electron density in the cloud from these measurements requires a number of assumptions about its shape. Backscatter radar measurements, on the other hand, measure the peak density only, and are liable to distortions if aspect-sensitive returns are present. There is no difficulty in measuring absolute electron densities to 10% throughout the cloud by means of rocket-borne probes.

(2) Presence of fine structure at early times. Optical and RF measurements are relatively insensitive to small intensities of fine structure in the cloud prior to the onset of visible striations, particularly for very small structure sizes. Probe techniques can readily detect structure size down to less than 100 m in the ionization distribution.

(3) Density distribution in the ambient ionosphere. The complex structure of the twilight electron distribution in the E and lower F regions cannot be mapped by a ground-based ionosonde, since the low electron densities

between 120 and 200 km may be completely masked by sporadic E in the 100-120 km region. Probe techniques have no problem in determining electron densities from 100 through 10^6 cm^{-3} in the ambient ionosphere; from these, integrated Pederson conductivities can be readily determined.

(4) Electric fields. Electric fields, inside and outside the cloud, inside and outside striations, and in special regions such as the ion wake, are important parameters in all theoretical models. These can be measured only with direct probe techniques.

The rocket probe experiment is described in more detail in Section 2. Section 3 describes some work on modelling a striated barium cloud, in which an analytical form is developed for the spatial distribution of the electron density.

2. Rocket Probe Measurements

2.1 Introduction

The objective of the probe experiment is to measure the electron density, ion density, electron temperature, and electric field with about 100-m resolution at two times in the history of a barium ion cloud--after the hard back edge develops, but before striations are visible; and after striations are clearly visible. Two types of information will come from the experiment: concerning the morphology of the barium cloud, and concerning the physics of its behavior. This information may be further detailed as follows:

(1) Morphological information

- (a) Absolute electron density distribution within the cloud
- (b) Nature of irregularities in electron density and electric field (if any) prior to the onset of visible striations
- (c) Shape and spacing of striations when visible from the ground
- (d) Nature of the hard back edge--namely, whether barium ions exist in substantial numbers outside the visible cloud (because of optical depth effects).

(2) Physical information

- (a) Nature of the mechanism producing initial distortion of the barium cloud
- (b) Magnitude and significance of internal electric fields in the cloud
- (c) Role of hydromagnetic convection in initiation and growth of striations.

To make the necessary measurements, attempts will be made to fly rocket payloads through one or more of the SECEDE II barium ion clouds. A total of six payloads are programmed. The carrier rocket is the Terrier-Tomahawk 9.

The principal instruments on each payload are a Langmuir probe, a plasma resonance probe, a three-axis electric field meter, and an ion density probe. Payload integration is the responsibility of the GCA Corporation under the direction of C. A. Accardo.

2.2 Langmuir Probe

Electron concentrations, gradients of electron concentration, and electron temperature are measured by an asymmetrical bi-polar Langmuir probe, instrumented by L. G. Smith of the GCA Corporation (Smith, 1967, 1968).

The smaller electrode of the Langmuir probe is the nose-tip of the rocket, of tungsten or Rene 41. The larger electrode is the conducting skin of both the payload and the Tomahawk rocket. The nose-tip electrode is driven at a potential ranging from -1.3 to +4.0 volts with respect to the rocket. The Langmuir probe operates in a 500 ms duty cycle; sweeping from -1.3 V to +4.0 V in 50 ms, and then maintaining a constant dc potential on the nose-tip of +4.0 V for 450 ms.

During the sweep mode, electron temperature is measured with an accuracy of about $\pm$ 25° kelvin. In the dc mode, electron concentrations are measured with a relative accuracy of about $\pm$ 2% and an absolute accuracy of about $\pm$ 10%. Fine-structure variations of the dc-probe current are proportional to gradients of electron concentration, and are able to resolve structure of the order of 100 meters in size.

2.3 Plasma Resonance Probe

Electron concentrations are also measured by a plasma resonance probe, instrumented by K. D. Baker of the University of Utah (Baker, 1969).

The plasma resonance probe consists of a hollow stainless steel tube, 1/4 inch in diameter and 1 meter in length. The tube serves as an antenna which is swept in frequency between 2 and 17 MHz at a rate of 16 times per second.

The parallel resonance frequency, f_R, marked by a zero phase angle between the antenna current and voltage, is a function of only the plasma parameters and is not a function of electron temperature and antenna parameters;

$$f_R^2 = f_N^2 + f_H^2 \qquad \text{where}$$

$$f_N = (1/2\pi)\sqrt{Ne^2/\varepsilon_o m} \quad \text{and} \quad f_H = Be/2\pi m.$$

The range of sensitivity of the plasma resonance probe is from N = 5 x 10^{12} to 2 x 10^{13} electrons m^{-3}, with an estimated accuracy of $\pm$ 5%.

In principle, electron temperatures can be deduced from the series resonance frequency of the antenna, but this measurement is not so direct or accurate.

2.4 Three-Axis Electric Field Meter

The electric field strength vector in the barium ion cloud is measured by a three-axis electric field meter instrumented by F. S. Mozer of the University of California at Berkeley (Mozer, 1969).

Potential differences are measured between four 5-cm diameter carbon-coated spheres by an electronic system having an input impedance of 10^8 ohms. Two of the spheres are held 3 meters apart on a line, by symmetrical booms

which are perpendicular to the axis of the payload. The two remaining spheres are also held 3 meters apart on a line, by symmetrical booms which are perpendicular to both the axis of the payload and the line passing through the first two spheres. Thus, the line passing through the first two spheres, the line passing through the second two spheres, and the axis of the payload are mutually perpendicular. The separation of the upper and lower booms, measured along the payload axis, is about one meter.

An ambient field of the order of 1 mV/m, and variations of about $\pm$ 0.1 mV/m corresponding to structures ranging from 100 to 500 meters in size are anticipated. Measurements at these levels are extremely difficult, and require meticulous management of experimental details such as precise measurement of the relative and earth-related positions and motions of the spheres and of changes in their contact potentials.

A measurement accuracy of 1 mV/m requires knowledge of the payload velocity with an accuracy of about 10 m/s, and of payload attitude with an accuracy of about 1/2 degree.

The optimum angle of the trajectory in the cloud with the geomagnetic field direction is about 12°. The ability of the instrument to measure the electric fields in question diminishes for smaller or larger angles.

The electric field, $\vec{E}'$, measured by the instrument, moving with the rocket, is related to the electric field, $\vec{E}$, one would measure in an earth-fixed frame of reference by

$$\vec{E}' = \vec{E} + \vec{v} \times \vec{B}$$

where $\vec{v}$ is the rocket velocity and $\vec{B}$ represents the earth's magnetic field. The vector subtraction of $\vec{v} \times \vec{B}$ from $\vec{E}'$ to obtain the electric field of

interest requires knowledge of the vehicle velocity vector, the earth's magnetic field vector, and the absolute orientation of the sensors in the earth's magnetic field. The vehicle velocity is given from radar data to an accuracy of ∿ 0.003 percent, and the earth's magnetic field vector is known over Florida to an accuracy of 0.05 percent from satellite surveys. The major uncertainty in the determination of the electric field in the earth-fixed frame of reference will come from uncertainties in the vehicle attitude. The vehicle attitude must be known so that the instantaneous electric-field components measured on the spinning rocket can be transformed to the non-rotating or non-tumbling frame of reference in which $\vec{v}$ and $\vec{B}$ are known.

2.5 Ion Density Measurement

The University of California also provided a detector on the probe rockets that measured parameters of the ionic component of the plasma in the following way. Four rectangular surfaces having a total area of 20 cm^2 were biased five volts negatively with respect to the rocket skin, and the current collected from the plasma by this surface was measured. This current, I, is given by

$$I = Anf(n,T,V) \left(\frac{kT_i}{2\pi m_i}\right)^{1/2}$$

where A = Area of the collecting plates

n = Plasma charge density

T_i = Ion temperature

m_i = Ion mass

k = Boltzmann's constant

f(n,T,V) = A slowly varying function of plasma density, temperature, and the voltage on the colecting plate, that represents the focusing of the ions onto the collector.

2.6 Supporting Instruments

A solar aspect sensor measures the angle between the longitudinal axis of the payload and the direction to the sun within $\pm$ 1/2 degree.

A single-axis magnetometer, measuring the geomagnetic flux density component in a direction parallel to the electrode of the plasma resonance probe, and also parallel to the foremost line of spheres of the electric field meter, serves the requirements of both instruments.

An aspect magnetometer senses the rotation rate of the payload, 1.5 to 2 Hz after de-spin.

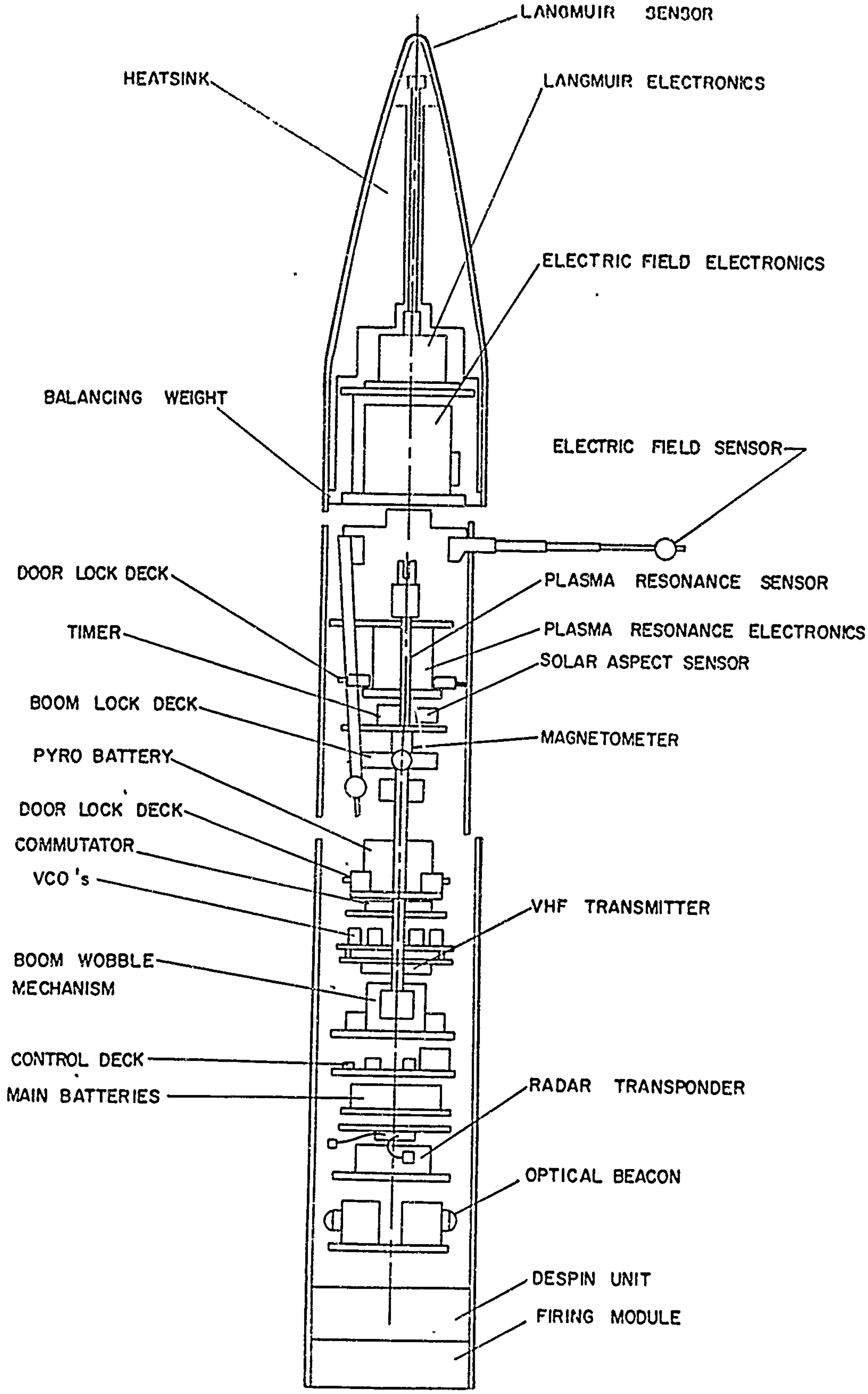
Four (possibly only two) xenon lights, flashing at a rate of one flash/ 2 sec, are provided for precision optical tracking.

On the following page is a cutaway drawing of the probe payload.

2.7 Probability of Fly-Through

Based on the requirements of plasma theoreticians, L. M. Linson and G. Meltz, first priority is assigned to the flight of at least one successful payload through an ion cloud at an "early time", before striation of the ion cloud. Second priority is assigned to the flight of at least one successful payload through an ion cloud at a "late time", after striation of the ion cloud.

The probability of a given payload passing through the ion cloud and working successfully is estimated to be about 0.2. This small probability of success dictates that five available payloads be assigned to the 352-kg release (Event Olive). If one or more of the payloads remain after both the early time and late time fly-through objectives have been met, the remaining payloads will be assigned to the 48-kg release at 250 km (Event Redwood).



SEC D II FLYTHROUGH PROBE

2.8.1 Relationship to optical diagnostics

A relatively simple approach to the problem of interpreting optical data in terms of striation morphology is presented elsewhere in this report. There it is shown that striations tend to be smoothed out when they are optically superposed, thus delaying the onset of visible striations relative to their time of initial detectability by a probe experiment. Thus, the so-called "early probe" may well see well-developed striations that are not yet visible in the barium resonance radiation.

A further point of concern is that spatial resolution. In view of the expected approximately 80-m/sec velocity of the cloud, optical diagnostics that do not track the cloud continuously (and most of them come into this category) will need exposure times of less than one or two seconds if they are to match the resolution of the probes. Study of the PRESECEDE filter photographs suggests that improved instrumentation will be needed to reach this goal in the presence of grain noise.

2.8.2 Relationship to radio diagnostics

Without doubt, the most difficult problem in understanding the radio data is in interpreting the nature of the HF return from a striated barium ion cloud. It seems that two additional types of experiments could be instrumented, at little additional cost, to help in constructing a realistic model of the striated return:

(1) Measurement of the amplitude of the scattered radio signal at two or more points on the ground, spaced by a distance that would give about a half-wavelength path difference between returns from the fron and rear edges of the cloud.

(2) Measurement of the amplitude of the scattered signal at two spaced frequencies at the same place, the frequency spacing being chosen to give a phase difference of 180 degrees for the path represented by double the thickness of the cloud.

Both of these types of experiment give quantities related to the <u>spatial</u> properties of the scattering elements of the cloud, and would greatly improve our ability to produce an RF model.

2.9 Anticipated Event Matrix

Six probe rockets are being prepared for launch in late January at Eglin Air Force Base. The portion of the planned event matrix that pertains to the probe experiment is given below.

Event	Event Altitude (km)	P/L Weight (lbs)	Launch to Release Time (sec)	Probes	Probe Launch Time(sec)	Probe Transit Time(sec)
Spruce	400	270	$R = T_o + 278$	(none)		
Nutmeg[1]	150	278	(101) $R = T_o + 160$	(none)		
Plum	185	278	$R = T_o + 126$	I	R + 327	R + 450
Olive	185	1556	$R = T_o + 179$	II	R + 327	R + 450
				III	R + 417	5 + 540
				IV[2]	R + 597	R + 720
				V[2,3]	R + 777	R + 900
				VI[2,3]	R + 957	R + 1080
Redwood	250	278	$R = T_o + 188$	V	R + 268	R + 450
				VI	R + 538	R + 720

1. On Nutmeg the Ba is not the first rocket to be launched in the event. Launch is at T_o + 59 seconds.

2. Probes IV, V and/or VI to be held for "late time" transversal if any of the preceding probes show transit through the Ba^+ cloud.

3. Probes V and/or VI to be held for Event Redwood if any of the preceding probes show transit during "late time".

3. Analytical Model for Barium Cloud Striations

As mentioned in Section 1, experiments involving the transmission of radio waves through a striated barium cloud, and measurements of the optical emission, both give results related to the integrated electron density along the line of sight through the barium cloud. Since the striation structure is aligned along the earth's magnetic field, a view directly up the field line will show the detailed structure of a striated cloud; however, the view obtained is generally at some other angle, often approaching 90 deg to the magnetic field, when the effects of the various striations are superposed in a way that makes it difficult to disentangle the structure.

In this section work is reviewed presenting an analytical basis for apparent degradation in striation structure that occurs when the structure is viewed off-axis.

3.1 Photometry of Ionized-Barium Cloud Photographs

In a previous publication (Bowhill 1970) detailed photometric studies were made of photographs of the PRESECEDE release KUMQUAT, and it was shown that grain noise prevented detection of any optical structure with apparent dimensions less than about 1 km. The autocorrelation function of the transmittance transverse to the striation axes was

$$\rho(x) = \exp[-(x/0.32)^2/2]$$

where x is distance normal to the field line in km.

In the later history of the cloud, the striation structure becomes much more poorly defined; and the question arises as to the extent to which this results from lowering of the striations by their overlapping. This is discussed in the next section.

3.2 Specific Analytical Models

In the following model the electron density is described in a plane normal to the striation axes, under the assumption that the same pattern, translated along the field line, applies at all points in the cloud (this is exactly the assumption of field-alignment). The coordinates x and y are normal to the field line, y being in the direction of the line joining the ion cloud to the neutral cloud; the origin of coordinates being at the center of the cloud. The electron density N for this model is given by the expression:

$$N = N_0(1 + ae^{-by}\cos cx)e^{-(x^2 + y^2)/2} \quad .$$

The integral of the electron density along a straight line which passes the center of the cloud at the closest distance u, and at an angle ω to the x axis, is given by

$$\int N ds = \sqrt{2\pi}\, e^{-u^2/2}[1 + a \cos(cg)e^{-c^2\cos^2\omega/2 + b^2 \sin^2\omega/2 + bu \sin\omega}]$$

where $g = b \sin \omega \cos \omega - u \sin \omega$.

The first term in the square bracket above corresponds to the line integral for the unperturbed cloud, while the second term represents the perturbation P_m in the line integral due to the striations. It is easy to show that the maximum value for P_m is given by

$$P_m = \sqrt{2\pi}\, ae^{-u^2/2}e^{-b^2/2-c^2\cos^2\omega/2} \quad .$$

Clearly, therefore, the greatest value for P_m (that is to say, the most distinct striations) occur for $\omega = 0$, that is, the view directly along the y axis. If ω

increases , the striations gradually become less pronounced, disappearing at an angle of about 1/c radians.

A second distribution which is being studied in some detail involves rod-like striations, the distribution being given by

$$N = N_0[e^{-y^2/2} + a(1 + \cos cx)^n e^{-(y + b)^2 D^2/2}]e^{-x^2/2} .$$

Here, n determines the gradient at the edge of a striation relative to their separation, and D determines whether the cross section of an individual striation is circular or elliptical.

Computer studies of this model show that the relatively sharp cut-off angle is no longer a feature of the line-of-sight integral. These investigations are continuing.

References

Baker, K. D., E. F. Pound and J. C. Ulwick (1969) Digital plasma frequency probe for fine scale ionospheric measurements, Small Rocket Instrumentation Techniques, North-Holland Publ. Co., Amsterdam.

Bowhill, S. A. (1970) Photometry of ionized-barium cloud photographs,"Ion Cloud Modeling and Characteristics" Vol. IV Project SECEDE 1970 Summer Study Proceedings, pp 169-186.

Mozer, F. S. (1969) Instrumentation for measuring electric fields in space, Small Rocket Instrumentation Techniques, North-Holland Publ. Co., Amsterdam.

Smith, L. G. (1967) Langmuir probes for measurements in the ionosphere, Electron Density and Temperature Measurements in the Ionosphere (edited by K. Maeda) COSPAR Technique Manual Series.

Smith, L. G., L. H. Weeks and P. J. McKinnon (1968) Rocket observations of electron temperature in the E-region, J. Atmosph. Terr. Phys., 30, 1301-1312.